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Enhancement of Water Electrolyzer Efficiency

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Abstract

In this project, factors affecting efficiency of water electrolysis such as the electrolyte type, electrodes spacing, electrodes surface morphology (smooth or rough), electrodes effective area (or number of electrodes) and electrodes connection configuration were investigated. The efficiency was calculated as the ratio between the HHO flow rate measured experimentally to that measured theoretically from Faraday's law. It is found that the best efficient electrolyzer consists of 22 plates (4 anodes, 4 cathodes and 14 neutrals) where each plate area was 17x15 cm^2. When the 22 plates were connected in parallel and immersed in 20 g KOH/3L electrolyte, they produced HHO gas flow rate of 740 ml/min at 17 A and 62.92 % efficiency.

Keywords: Energy, HHO, Hydrogen, Electrolysis, Efficiency, Environment.

1. Introduction

Electrolysis of water for hydrogen production has been known since the early nineteenth century. In the electrolysis process that is used in this project, hydrogen and oxygen are produced at the same time and collected as a mixture to be used as a fuel.

In the electrolysis process, a direct current is passing through water between two electrodes (anode and cathode). The electric current will then dissociate the water into hydrogen and oxygen gases that are collected as a mixture called HHO.

Electrolysis process is considered a promising technology for the production of clean and sustainable source of energy because it uses water as the main raw material and needs very small energy (electricity) to produce valuable fuel (HHO) without any abuse to the environment (Le et al. 2010, Afgan & Veziroghu 2010, Barton & Gammon 2010). Production of hydrogen without fossil fuel-based processes is one suitable alternative solution in the near future (Grani'a et al. 2007, Gomes Antunes et al. 2009, Corbo et al. 2010, Zhang & Zhou 2011). One of the most popular research areas in hydrogen production by utilizing renewable energy sources is the efficiency enhancement of the electrolysis process by means of reducing the electric power consumption in the electrolyzer. Many factors have been studied to reach elevated levels of current densities by maintaining or even reducing the electrolysis cell voltage. Galney (2009) studied the electrolysis process efficiency of a high temperature and pressure electrolyte. He found that an acceptable fall in the amount of required voltage in the case of targeting any given current density is achieved at atmospheric pressure and temperature levels between 200 ^oC and 400 ^oC. On the other hand, Nagi et al. (2003) expressed that conducting electrolysis in higher temperature decrease the equilibrium voltage of water because it enlarges the gas bubbles size and reduces their rising velocity. As a result, the void fraction in the electrolyte will increase and the efficiency will decrease. Mansouri et al. (2001) tried to increase the efficiency and lower the capital costs of hydrogen production by reaching higher current density in the conventional electrolyzers. They found that increasing electrolyte pressure leads to less power consumption as it reduces the diameter of produced gas bubbles. Therefore, the ohmic voltage drop and power dissipation between electrodes are reduced. Badwal et al. (2006) found that the pH of the water that is used as the electrolyte affected the required voltage to drive an electrolytic bath on a certain current significantly due to the conductivity of the electrolyte. On the other hand, it is well known that high acid or base concentration liquids have sever negative corrosion effects on the electrodes. Therefore, a balance between the pH and voltage is required. Petrov et al. (2011) found that 25-30% KOH solution is the most suitable concentration in the electrolysis processes. Mazloomi and Nasri (2012) have analyzed several factors influencing water electrolysis efficiency by studying available verified information in electrical, electrochemical, chemical, thermodynamics and fluid mechanics fields such as distance between electrodes, their size, alignment and shape.

In this study several factors affecting the amount of hydrogen and oxygen gas produced by the electrolysis of water will be investigated as a function of input power such as electrolyte type, electrodes spacing, electrodes surface morphology (smooth or rough), electrodes effective area (or number of electrodes) and electrodes connection configuration. This is expected to improve the efficiency of the electrolysis process by producing more gas per watts.

2. Experimental setup and procedure

Figure 1 shows a complete setup consisting of a Plexiglas container containing the electrolyte and the electrodes that are connected to the 12 V battery in order to provide the cell with the required current for electrolysis. The cathodes and anodes were manufactured from stainless steel 316L. The plate electrodes dimensions were (17 cm length, 15 cm width and 1 mm thickness) while the tubes dimensions were (15 cm height, 1 cm inner diameter and 1 mm thickness). The spacing between the anodes and cathodes in both designs was 2-3 mm.

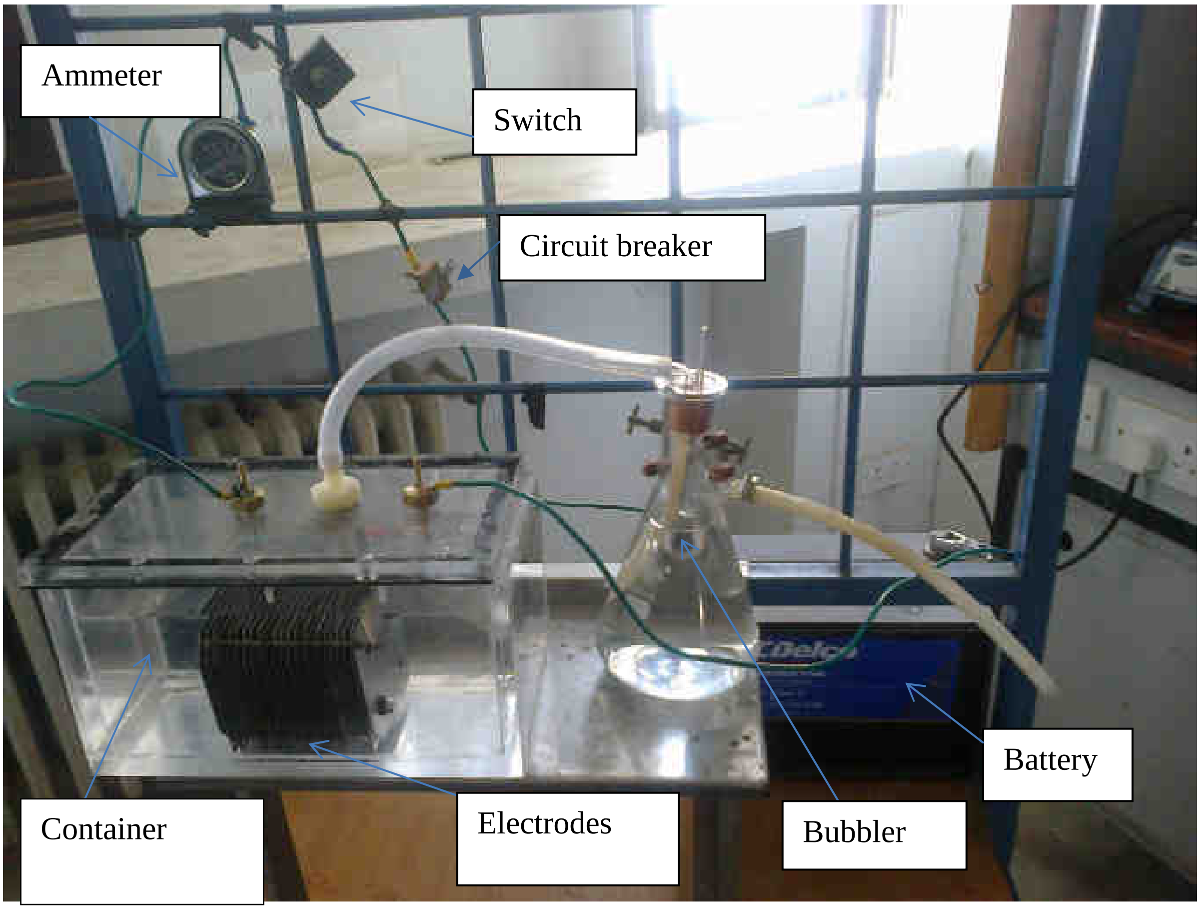


Figure 1: The electrolysis setup showing the Plexiglas container, the electrodes, the electrolyte and the bubbler.

The electrical current was measured by an Ammeter connected in series with the circuit. The bubbler was connected right after the electrolyzer and used as a safety piece. When the HHO gas comes out of the electrolyzer, it goes through the bubbler which is filled with a liquid (usually water or vinegar) and out of the other end to be used from there. Therefore the bubbler cools the warm gas and cleans it from any electrolyte particles going out with gas. It is important to use a non-return valve between the electrolyzer and the bubbler to prevent bubbler water being pushed back into the electrolyzer in case of backfire.

Before using the electrodes for the first time, they were pretreated or activated because smooth surfaces would not produce significant quantity of HHO without activation. Therefore, the electrodes left unused in the KOH solution for 24 hour in order to receive a white coating. Once the power was first applied, very little electrolysis took place as the active surfaces get covered with bubbles which stick to them and a scum was formed on the water surface. After cleaning the scum and repeating the process few times, the scum no longer forms and the active electrodes surfaces had the white coating.

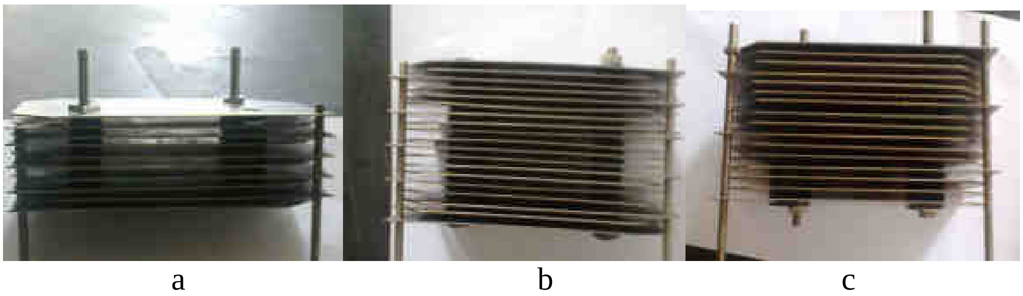
2.1 Flow Rate Measurement Method

The HHO flow rate was measured by calculating the water displacement per time according to the setup shown in Figure 2. The HHO leaving the electrolyzer and going into the water flask bushing the water down, and then the water going up through the tube, leaving to the graduated cylinder. The volume of water collected in the graduated cylinder per unit of time was measured as the HHO flow rate.

Figure 2: The setup for measuring the HHO flow rate.

2.2 Electrodes Designs or Configurations

Figures 3a,b,c show three different electrolyzers designs with rectangular plates of 5 anodes, 5 cathodes without any neutrals (5C5A0N), 5 anodes, 5 cathodes and 9 neutrals (5C5A9N) where one neutral plate was inserted between each cathode and anode and 3 cathodes, 3 anodes and 10 neutrals (3C3A10N) where two neutral plates were inserted between each cathode and anode, respectively. Figure 4 shows another electrolyzer design with six cylindrical cathodes and six cylindrical anodes connected together in parallel.



a b c

Figure 3: Plate electrodes connected in parallel, a) 5C5A0N; b) 5C5A9N; and c) 3C3A10N.

Figure 4: Cylindrical electrodes connected in parallel.

3. Results and Discussion

In this project a study to enhance the efficiency of HHO gas production from water by electrolysis was conducted taking into account the effect of, electrolyte type and concentration, electrodes spacing, electrodes surface morphology (smooth or rough), electrodes connection configuration and electrodes effective area (number of electrodes) on the amount of HHO gas flow rate production and electrolyzer efficiency.

Using Farady's first law of electrolysis (eqn. 1), the theoretical amount of HHO flow rate in liter per hour for one *cell was calculated.

$$V = \frac{R.I.T.t}{F.P.z} \tag{1}$$

Where V is the volume of gas in Liters (L) per one cell, R is the ideal gas constant (0.082 L.atm/mol.K), I is the electrical current in Amber (A), T is the temperature of the solution in Kelvin (K), t is the electrolysis time in seconds (s), P is the ambient pressure in atmosphere (atm), F is Faraday's constant (96500 C/mol) and z is the number of excess electrons (2 for H_2 and 4 for O_2).The electrolyzer efficiency is usually calculated based on the ratio of the amount of the gas flow rate measured experimentally and that calculated theoretically from Faraday's law.

In this project, an electrical power was discharged into the water which was decomposed into hydrogen and oxygen. The measured flow rate was composed of both hydrogen and oxygen together. This means the volume calculated from Faraday's law is equal to the volume of both gases in which the amount of hydrogen produced is twice that of oxygen because each mole of H_2O is dissociated to produce 2 moles of H_2 and 1 mole of O_2.

3.1. Electrodes Connection Configuration:

Low current below 20 A was achieved by controlling the electrolyte concentration for different electrodes shapes and configurations. It is clear from Table 1 that the use of plates electrodes is better than using cylindrical electrodes due to the increase in the active surface area, hence increasing gas flow rate production at lower electrical current. It is also obvious that plates electrodes showed higher efficiency than that for cylinders in addition to higher HHO flow rate.

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Table 1: Electrodes Connection and Configuration at low current

Connection	Electrolyte	Current (A)	Flow rate (ml/min)	Efficiency %
5C5A0N	2 g KOH/3L	13	209	15.92
5C5A9N	3 g KOH/3L	10	216	21.39
3C3A10N	10 g KOH/3L	11	352	57.04
1 cylinder	0.5 g KOH/3 L	7	86	44.57
2 cyl in parallel	0.5 g KOH/3L	10	120	35.65
3 cyl in parallel	0.5 g KOH/3L	13	190	26.05
2 cyl in series	0.5g KOH/3L	13	50	11.42
3 cyl in series	0.5 g KOH/3L	16	90	10.03

It is clear that the maximum gas flow rate was 190 ml/min for 3 cylinders connected in parallel where the current was 13 A. Increasing the number of cylinders increased the gas flow rate and the current simultaneously. Comparing with the plate design, higher gas flow rate (352 ml/min) was achieved in the 3C3A10N at low current (11 A). The connection of cylindrical electrodes in series obtained lower current but lower gas flow rates.

3.2 Electrolyte Type and Concentration

It is obvious from Table 2 that tap water is good in terms of cost, current and gas flow rate but it is not preferable due to the corrosion effect on the elctrolyzer. The comparison between Sodium Carbonate and Potassium Hydroxide shows that 174 ml/min was produced using Sodium Carbonate at 20 A and 20 plates while 209 ml/min was produced at 13 A using Potassium Hydroxide and 10 plates only. Therefore, KOH is preferable.

Table 2: Different electrolyte types for electrodes 10C10A0N & 5A5C0N

Connection	Electrolyte	Current (A)	Flow rate (ml/min)	Efficiency %
10C10A0N	Tap water	11	200	8.53
10C10A0N	3 g Sodium Carbonate/3L	20	174	4.08
10C10A0N	0.5g KOH/3L	20	250	5.86
5C5A0N	2 g KOH/3L	13	209	15.92

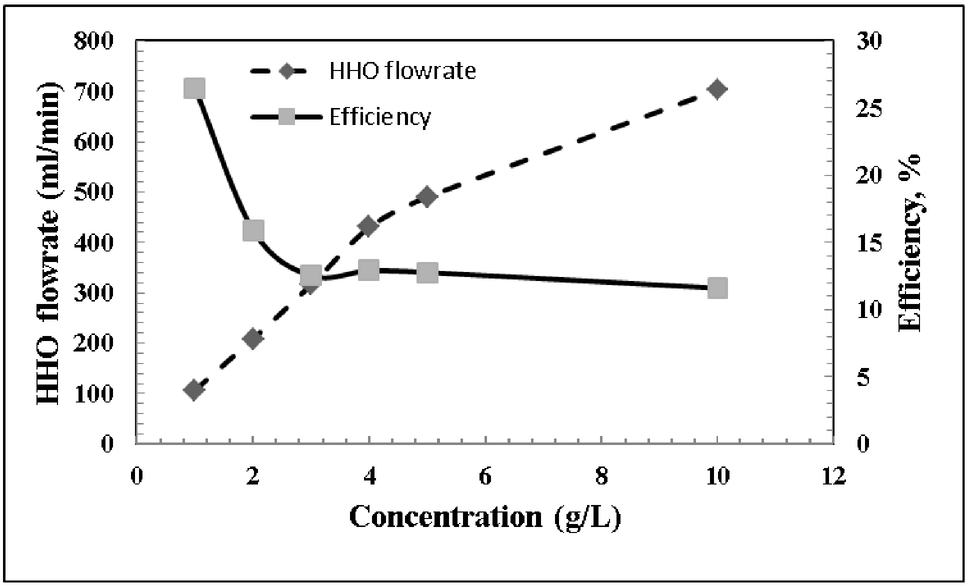

Figure 5: KOH Electrolyte concentrations for electrodes design 5C5A0N.

The addition of electrolyte to the pure water is a must because of its low electrical conductivity which is not enough to produce significant amount of HHO. Using one plates configuration such as 5C5A0N, shows that the increase in KOH electrolyte concentration, increases the HHO gas flow rate due to higher ionization and electrical current while decreasing the efficiency as shown in Fig. 5.

3.3 Electrodes spacing

It was very difficult practically to change the electrodes spacing, therefore the spacing of 2-3 mm (the best spacing in the literature) was fixed during all the experiments.

3.4 Electrodes Effective Area

As shown in Table 3, it is found that when one neutral plate was inserted between each anode and cathode, the amount of HHO gas flow rate produced was increased and the electric current was decreased. This is clear in the electrodes design 5C5A0N and 5C5A9N. The efficiency was further enhanced significantly by adding two neutral plates between each cathode and anode as shown in the case of 3C3A10N configuration. This means that at any concentration, the current decreased and the efficiency increased with the increase of the number of neutral plates between the electrodes. The best number of neutral plates is two plates because for more than two plates, the current will drop significantly to a value that is not enough to dissociate the water into oxygen and hydrogen, and then will not produce significant quantities of HHO gas.

Table 3: Electrodes designs and configurations

Connection	Electrolyte	Current (A)	Flow rate (ml/min)	Efficiency %
5C5A0N	2.5 g KOH/3L	20	270	13.37
5C5A0N	5 g KOH/3L	38	490	12.77
5C5A0N	10 g KOH/3L	60	703	11.60
5C5A9N	5 g KOH/3L	20	403	19.96
5C5A9N	10 g KOH/3L	30	507	16.74
5C5A9N	15 g KOH/3L	45	660	14.53
3C3A10N	5 g KOH/3L	7	238	60.61
3C3A10N	10 g KOH/3L	11	352	57.04
3C3A10N	15 g KOH/3L	20	634	56.51

3.5 Electrodes Surface Morphology

It is obvious from Fig. 6 that increasing the roughness of the electrodes plates where cross-hatch pattern was engraved on the plates using different emery sand papers with grades (1200, 800, 400, and 180), the HHO gas produced and the efficiency were increased with the decrease in the number of emery sand paper. This means more rougher surfaces lead to more HHO production and more efficiency due to the increase in the surface area.

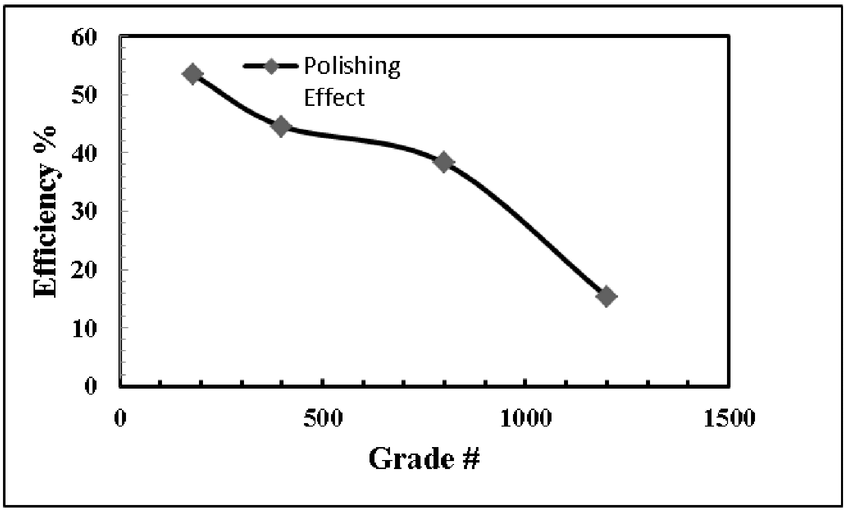

Figure 6: Surface roughness for electrodes design 5C5A0N.

3.6: Optimum Efficiency

After deciding the best electrodes shapes (plates), electrodes polishing number (# 180), electrodes connection method (parallel), and a reasonable electrolyte concentration that give low current (10 to 20 A), one has to find the best parameters that give the highest HHO gas production flow rate at the lowest possible current, hence the highest efficiency. As shown in Table 4, the best electrode design will be 4C4A14N, with 20 g KOH/3L which produced 740ml/min of HHO at low current (17 A) and high efficiency about 69.92 %.

Table 4: The optimum electrolyzer design parameter

Connection	Electrolyte	Polishing #	Electrodes spacing (mm)	Current (A)	Flow rate (ml/min)	Efficiency %
4C4A14N	20 g KOH/3L	180	2-3	17	470	62.92

Conclusions

The results from this project showed that the plate electrodes are more suitable than the cylindrical ones and the connection in parallel is better than that in series. Using neutral electrodes between the anodes and cathodes (2 neutral plates between each electrode) reduces the electric current without affecting the flow rate production significantly due to the increase in the effective area. It is found that the best efficient electrolyzer consists of 22 plates (4 anodes, 4 cathodes and 14 neutrals) where each plate area was 17x15 cm^2. When the 22 plates were connected in parallel and immersed in 20 g KOH/3L electrolyte, they produced HHO gas flow rate of 740 ml/min at 20 A and 62.92 % efficiency.

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